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# YAW CARD RANGE TESTS OF A 30mm FRANGIBLE TP PROJECTILE



BALLISTICS BRANCH
GUNS, ROCKETS AND EXPLOSIVES DIVISION

JANUARY 1976



FINAL REPORT: MARCH 1975 - SEPTEMBER 1975



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Experimental results of yaw card range test of a 30mm frangible TP projectile are presented. Results include experimentally determined static and dynamic stability derivatives and drag coefficients obtained at a free-flight Mach number of 3.02.

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## PREFACE

The work documented in this report was done at the request of the Guns and Rockets Branch (DLDG), Gun, Rockets and Explosives Division (DLD), Air Force Armament Laboratory (AFATL), Eglin Air Force Base, Florida 32542, under Project 670F0104.

The results were obtained intermittently from March 1975 to September 1975 at the Ballistic Experimentation Facility (BEF) Yaw Card Range, Eglin Air Force Base, Florida.

Acknowledgement is made for the considerable time and effort expended by Mr. G. L. Winchenbach (DLDL) on the data reduction required for this report.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

GERALD P. D'ARCY, Colonel, USAF
Chief, Guns, Rockets and Explosives Division





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## SECTION I

## INTRODUCTION

There has long been a need for a target practice projectile which has flight characteristics similar to those of an all up round but which breaks up into small, high drag fragments upon impact. This fragmenting characteristic is desirable from the viewpoint of aircraft safety since an ideal target projectile should have a zero probability of a ricochet hit on the strafing aircraft. It is also desirable from the range ground safety aspect since a small projectile ricochet ground foot print reduces the test range size requirements.

As part of an effort to develop a low cost fragmenting projectile, free-flight tests have been conducted to obtain preliminary estimates for the aerodynamic drag and stability characteristics of a 30mm plastic frangible TP projectile. Yaw card testing techniques were utilized to obtain the downrange position and attitude of the projectile in flight. These tests were part of a larger test program conducted to verify the structural integrity of the projectile. However, this report contains only data pertinent to the aerodynamic characteristics of the projectile.

This technical report discusses the test procedures and aerodynamic data for 30mm frangible TP projectiles at a Mach number of 3.0.

## SECTION II

## APPARATUS AND PROCEDURE

### 1. YAW CARD RANGE

The free-flight tests of the 30mm frangible TP projectiles were conducted on the Ballistic Experimentation Facility (BEF) Yaw Card Range, which is an outdoor range located on Test Area A22 at Eglin Air Force Base. The yaw card range (Figure 1), which is described in detail in Reference 1, was equipped with 20 yaw cards spaced at random increments along its 250-foot length. The yaw cards, which consisted of 24 by 30 inch single weight photo papers positioned perpendicular to the gun boresight line, were mounted with the exposed emulsified surface facing the gun. The yaw cards were used to record the downrange position and attitude of the projectiles in flight at each yaw card station. These data were used in the analysis of the projectile angular motion as described in Section III.

The velocity histories of the projectiles were determined from measurements of the times at which the projectiles penetrated sheets of circuit paper which were used to complete the timing circuits of the velocity instrumentation system. A schematic diagram of the velocity measurement instrumentation system is shown in Figure 2. As shown in the schematic, penetration of the circuit paper at the first velocity station starts the timers at all downrange stations. As the projectile penetrates each downrange circuit paper, the timing circuit counters for each station are stopped sequentially, thus giving consecutive times of flight as measured from the first station.

### 2. MODEL MEASUREMENTS AND TEST CONDITIONS

A schematic drawing of the 30mm plastic frangible TP projectiles tested for this report is shown in Figure 3. These projectiles consisted of a 30 percent glass reinforced nylon 12 skin, 50 zinc phosphated punched steel washers in four sizes, a zinc phosphated steel end-cap, and a 50 percent glass reinforced nylon 12 nose/filler piece.

The nominal mass property measurements of the projectiles tested are given below:

| M (gms) | $I_x$ (gm-cm$^2$) | $I_y$ (gm-cm$^2$) | cg (percent ℓ from nose) |
|---|---|---|---|
| 357.0 | 284.8 | 3666.1 | 63.7 |

These nominal physical measurements were used to reduce the data obtained from each round.

Other pertinent exterior dimensions are given in Figure 3. ID and OD tolerances were maintained at ±0.005 inch TIR to maintain dynamic balance within the projectile.

The projectiles were loaded into standard GAU-8/A cartridge cases with 144 grams of CIL 3331 propellant and 1 gram of FFG black powder and fired from a GAU-8/A Phase II constant twist (202.6 deg/ft) Mann barrel. Average projectile muzzle velocity was 3370 ft/sec with an average chamber pressure of approximately 54,000 psi. Of the 20 test shots fired for the purpose of obtaining yaw card data, nine projectiles produced yaw cards with sufficient hole definition to allow for data reduction.

## SECTION III

## DATA ANALYSIS

### 1. YAW ANALYSIS

The attitude histories of the 30mm projectiles were derived from measurements of the holes cut by the projectiles as they passed through the yaw cards. The measurements required for the attitude determination were the hole length, $\ell_c$, and the longitudinal axis orientation angle, $\phi_c$, which are shown in Figure 4.

Since the length of the hole is a direct function of the total angle of attack of the projectile as it passed through the yaw card, the total angle of attack, $\alpha_T$, could be determined from the measured hole length. This was accomplished with the aid of Figure 5 which shows the hole length as a function of total angle of attack. The data of Figure 5 were obtained by using an optical comparator to measure the length of the orthographic projection of the 30mm frangible TP projectile at various angles of attack.

Once $\alpha_T$ and $\phi_c$ were obtained, the missile angles $\alpha$ and $\beta$ required by the data reduction program were computed. These angles were computed by assuming that the projectile velocity vector was coincident with the earth fixed reference axis established by the gun boresight such that the missile angles $\alpha$ and $\beta$ are equal to the earth-fixed angles $\theta$ and $\psi$. This assumption is reasonable in view of the high speed and short flight path of the projectile. The relationship between the angles $\alpha$, $\beta$, $\alpha_T$ and $\phi_c$ is depicted in Figure 4. Therefore:

$$\beta = \psi = \alpha_T \sin\phi_c \qquad (1)$$

$$\alpha = -\theta = -\alpha_T \cos\phi_c \qquad (2)$$

After $\alpha$ and $\beta$ were obtained from each yaw card, the equation:

$$\beta + i\alpha = K_1 \exp\left[\eta_1 + i(\omega_1 + \omega_1' x)x\right] + K_2 \exp\left[\eta_2 - i(\omega_2 + \omega_2' x)x\right] \qquad (3)$$

was fitted to the $\alpha$, $\beta$ and x history using a least squares technique to obtain the coefficients $K_1$, $K_2$, $\eta_1$, $\eta_2$, $\omega_1$, $\omega_2$, $\omega_1'$, and $\omega_2'$. Equation (3) is a modified linear theory closed form solution for the angular motion of a symmetric missile in free-flight at small angles of attack. This equation is valid for projectiles which exhibit a linear variation of aerodynamics with angle of attack and a linear variation of roll rate with distance along the flight path. A complete derivation and discussion of Equation (3) is given in Reference 2. The stability derivatives, $C_{m_\alpha}$, $C_{m_{p_\beta}}$, and, $(C_{m_q} + C_{m_{\dot\alpha}})$ are functions of the determined coefficients (Reference 2).

These functions are:

$$C_{m_\alpha} = \frac{-2I_y}{\rho S_\pi d}\left[(\omega_1 + 2\omega_1' X)(\omega_2 + 2\omega_2' X)\right] \tag{4}$$

$$C_{m_{p_\beta}} = \frac{I_x}{d^2}\left\{\frac{2m}{\rho S_\pi}\left[\frac{-\eta_1(\omega_2 + 2\,\omega_2' X) + \eta_2\,(\omega_1 + 2\omega_1' X)}{(\omega_1 + 2\,\omega_1' X) - (\omega_2 + 2\omega_2' X)}\right] + C_D - C_{N_\alpha}\right\} \tag{5}$$

$$\left(Cm_q + C_{m_{\dot\alpha}}\right) = \left[\frac{2m}{\rho S_\pi}(\eta_1 + \eta_2) + C_{N_\alpha} - 2C_{D_T}\right]\frac{I_y}{md^2} \tag{6}$$

The values of these coefficients presented in Section IV represent the mid-flight values which were obtained by evaluating the above functions at $X = X_{\text{MID RANGE}}$.

## 2. DRAG ANALYSIS

The drag analysis used for projectiles fired on the yaw card range utilizes the multiple data set fitting technique of Reference 3. For each set of data, it is assumed that the instantaneous total drag coefficient, $C_{D_T}$, can be expanded as

$$C_{D_T} = C_{D_o} + C_{D_2}\,\alpha_T^2 + C_{D_4}\,\alpha_T^4 + C_{D_V}\,(V_{REF} - V) \tag{7}$$

where $\alpha_T$ is the instantaneous total angle of attack.

Therefore, the differential equation governing the longitudinal motion is:

$$\ddot{X} = \frac{-\rho V^2 S_\pi}{2m}\left[C_{D_o} + C_{D_2}\,\alpha_T^2 + C_{D_4}\,\alpha_T^4 + C_{D_V}(V_{REF} - V)\right] \tag{8}$$

if it is assumed that the angle between the velocity vector and X axis is small.

Using the multiple fit technique of Reference 3, the numerical solution to Equation (6) was fit to the multiple sets of drag data. This fitting technique utilizes the numerical integration technique of Reference 4. This was accomplished in such a manner as to provide a least squares fit solution for the constant coefficients of Equation (8) based on the values of $\alpha_T$ obtained from the yaw cards and of the X, t data obtained from the velocity measurement instrumentation system.

## SECTION IV

## RESULTS AND DISCUSSION

The aerodynamic data obtained from the testing of the 30mm frangible TP projectiles are presented in Table 1. Also tabulated are the arithmetic means for the listed values of the coefficients. On the basis of results presented in Reference 1, which compare data derived from yaw card tests at the BEF for a similar type projectile, the following error bands may be associated with the mean values of Table 1,

$$C_{m_\alpha} = 2.90 \pm 0.09, \quad \left(C_{m_q} + C_{m_{\dot\alpha}}\right) = -24.5 \pm 5.6,$$

$$\text{and} \quad C_{m_{p_\beta}} = 0.79 \pm 0.35.$$

Figure 6 shows the variation of the static stability derivative, $C_{m_\alpha}$, with the square of the effective angle of attack, $\delta_e^2$ which is defined in Reference (5). Since there is no variation of $C_{m_\alpha}$ with $\delta_e^2$ values up to 256.0 degrees$^2$, it may be concluded on the basis of the analysis of Reference 5 that nonlinear aerodynamic effects on static stability are not significant for angles of attack less than 16 degrees.

Although the spread in the measured values for $\left(C_{m_q} + Cm_{\dot\alpha}\right)$ and $C_{mp_\beta}$ may reflect variations of these derivatives with Mach number and/or $\delta e^2$, the spread most likely results from the uncertainty associated with the yaw card testing technique.

The zero lift drag coefficient listed in Table 1 is the value obtained when the data from all shots tested were analyzed simultaneously using the multiple fit technique described in Section III.

## LIST OF ABBREVIATIONS AND SYMBOLS

| | |
|---|---|
| $C_{D_T}$ | Total drag coefficient |
| $C_{D_0}$ | Zero yaw drag coefficient |
| $C_{D_2}$, $C_{D_4}$, $C_{D_V}$ | Coefficients of Equation (4) |
| cg | Center of gravity (percent length from nose) |
| $C_{m_\alpha}$ | Static stability derivative, 1/rad |
| $C_{m_{p_\beta}}$ | Magnus moment derivative, $1/\text{rad}^2$ |
| $\left(C_{m_q} + C_{m_{\dot{\alpha}}}\right)$ | Damping-in-pitch derivative $\frac{\partial C_m}{\partial q(d/2V)} + \frac{\partial C_m}{\partial \dot{\alpha}(d/2V)}$, $1/\text{rad}^2$ |
| $I_x$ | Model axial moment of inertia |
| $I_y$ | Model transverse moment of inertia |
| $K_1$, $K_2$ | Initial amplitudes of the projectile nutational and precessional vectors |
| $\ell$ | Model length (14.636 cm) |
| $\ell_c$ | Length of hole in yaw card |
| m | Model mass |
| $S_\pi$ | Reference area $\left(6.979\ \text{cm}^2\right)$ |
| $V_{REF}$ | Reference velocity of Equation (4) |
| V | Velocity in downrange direction |

## LIST OF ABBREVIATIONS AND SYMBOLS (CONCLUDED)

| | |
|---|---|
| X | Downrange distance |
| $\alpha_T$ | Total angle of attack |
| $\alpha$, $\beta$ | Missile fixed angles of pitch and yaw |
| $\rho$ | Air density |
| $\phi_c$ | Yaw card orientation angle |
| $\eta_1$, $\eta_2$ | Damping rates of the nutational and precessional vectors |
| $\omega_1'$, $\omega_2'$ | Rate of rotation of the nutational and precessional vectors |
| $\theta$, $\psi$ | Components of the earth-fixed complex yaw angle $\left(\frac{w}{V}, \frac{v}{V}\right)$ |

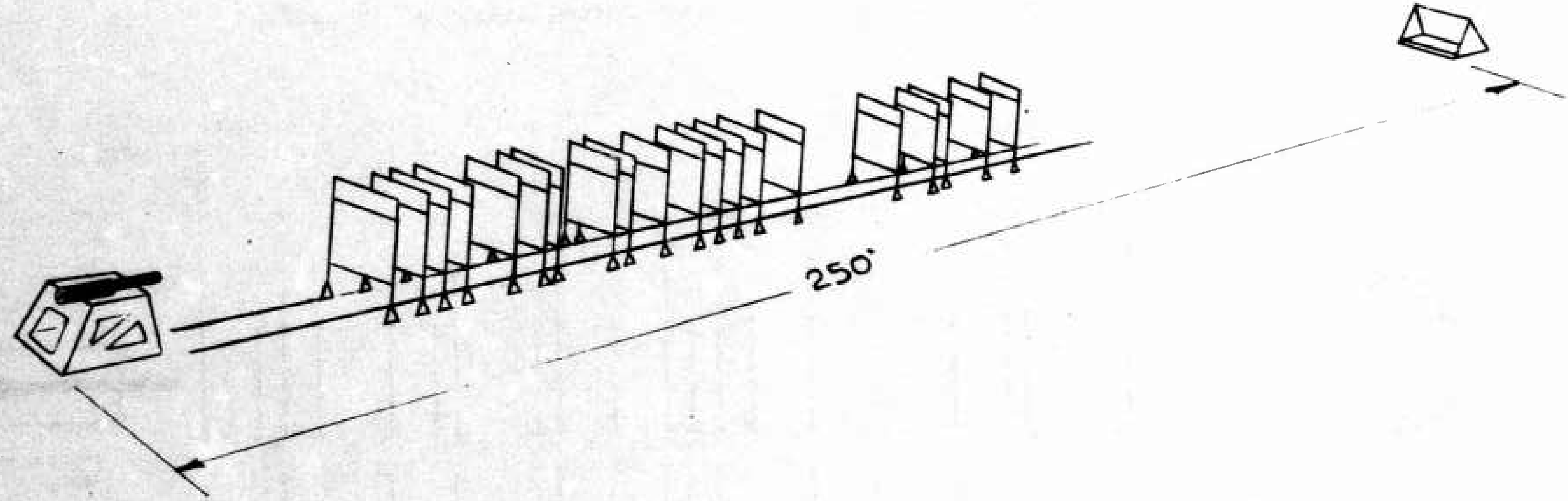



Figure 1. Ballistic Experimentation Facility (BEF) Yaw Card Range

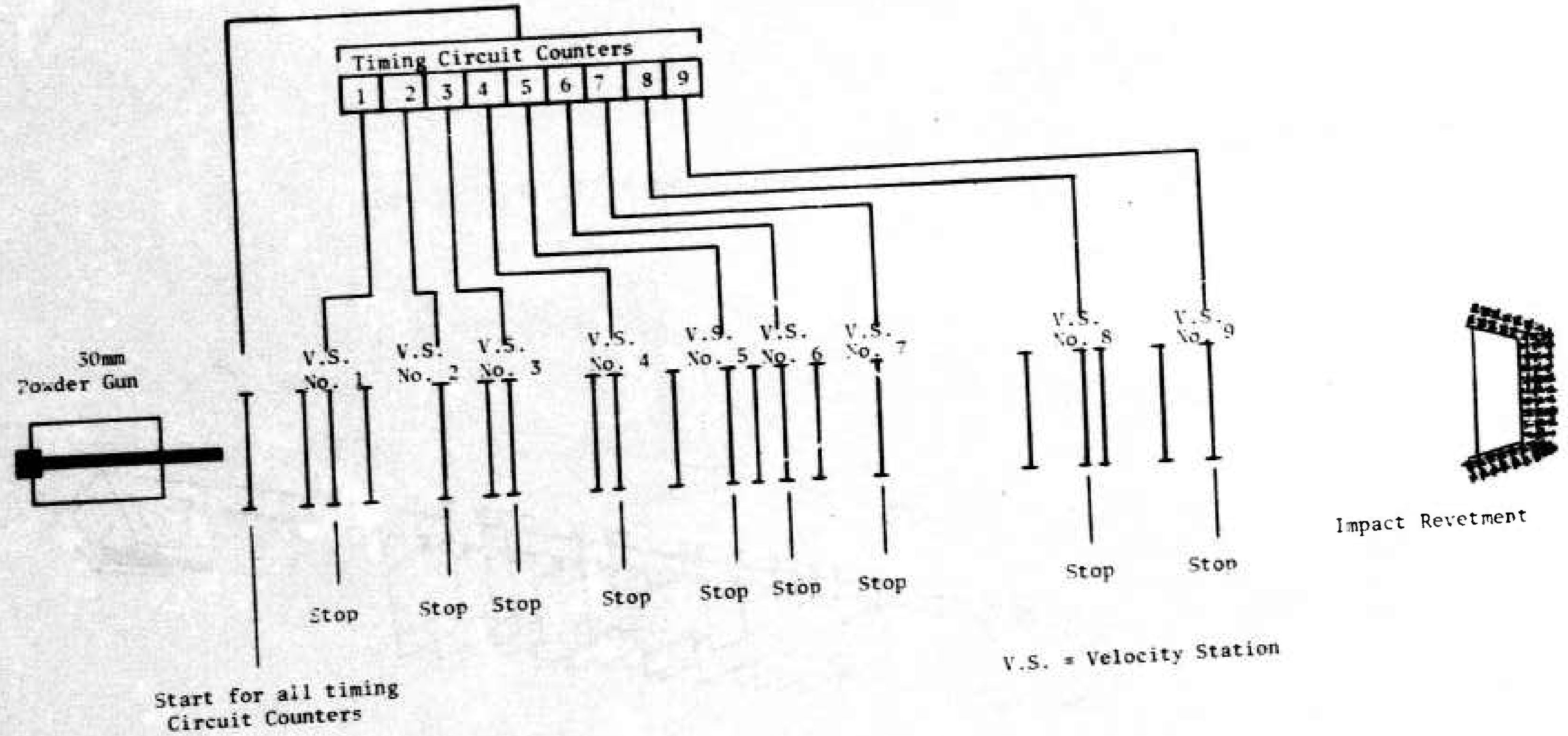
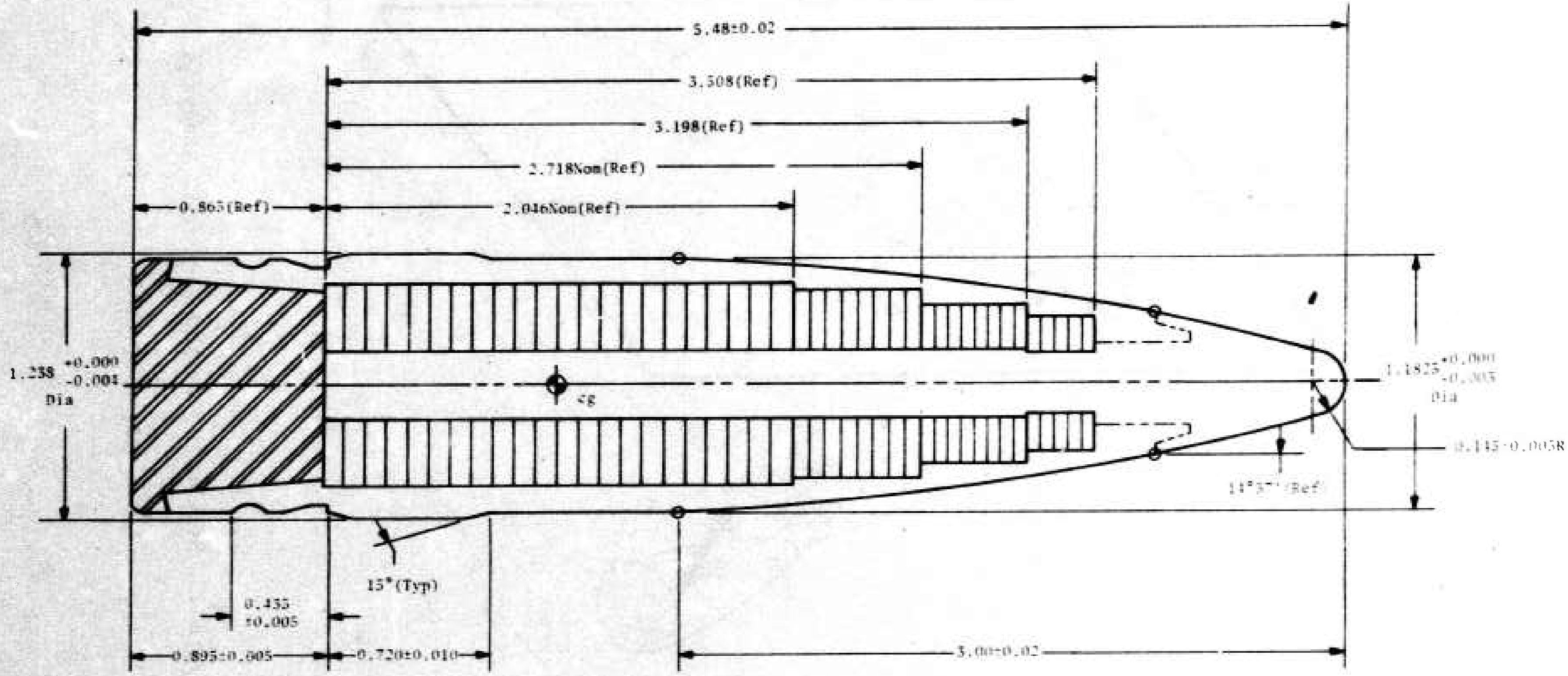



Figure 2. Velocity Measurement Instrumentation System Schematic




All dimensions are in inches

Figure 3. 30mm Plastic Frangible TP Projectile

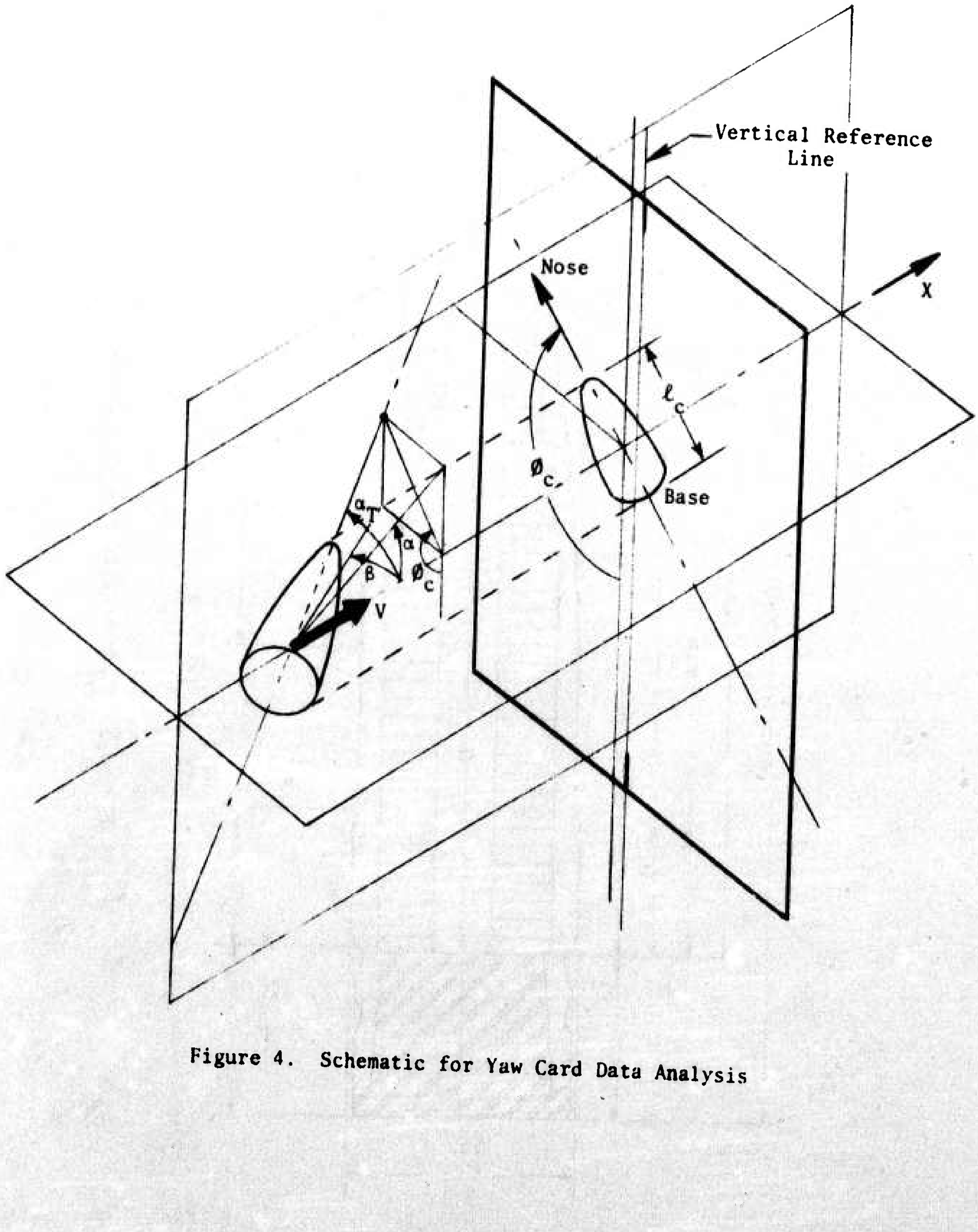



Figure 4. Schematic for Yaw Card Data Analysis

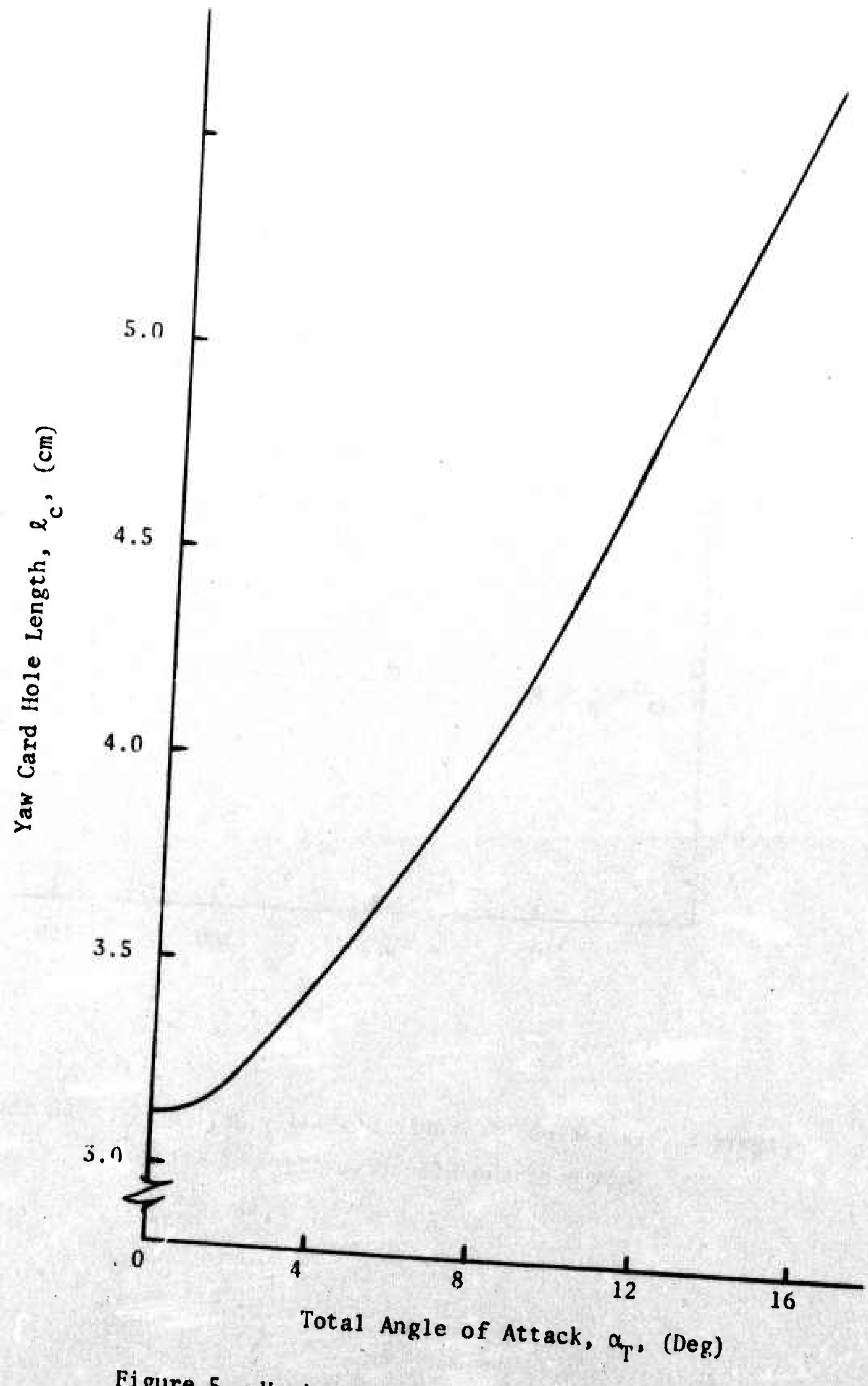



Figure 5. Variation of Yaw Card Hole Length with Total Angle of Attack

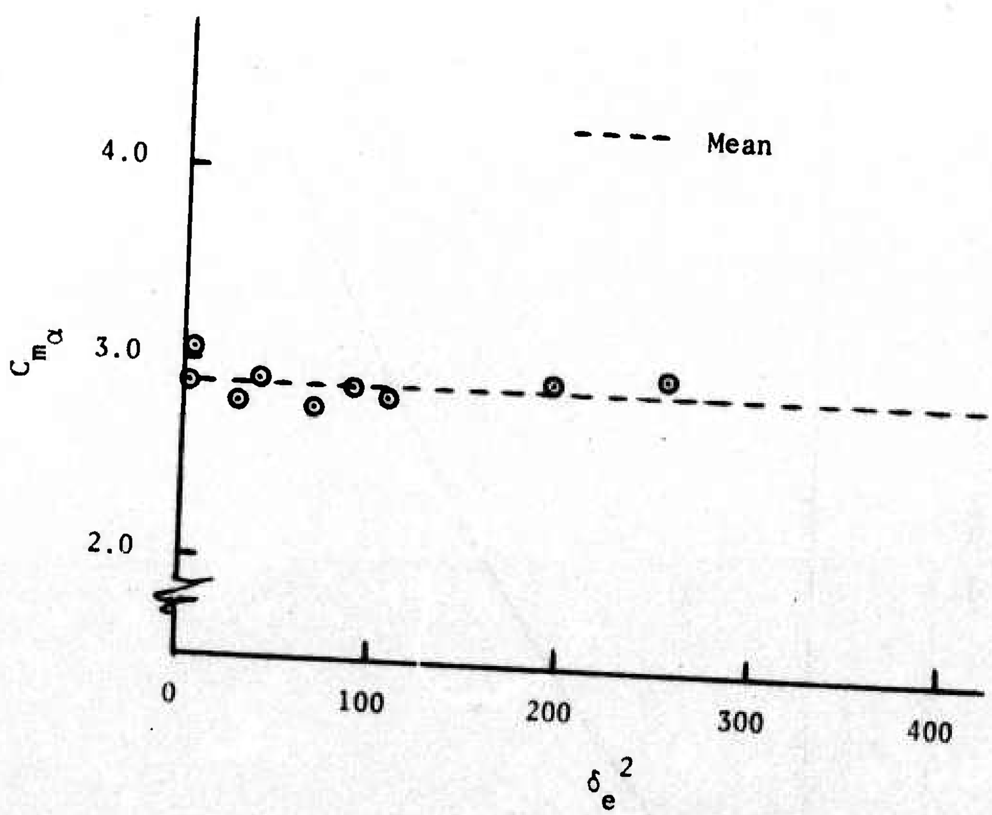



Figure 6. Variation of Static Stability Derivative with the Square of the Effective Angle of Attack

TABLE 1. 30MM PLASTIC FRANGIBLE TP PROJECTILE FREE-FLIGHT AERODYNAMIC CHARACTERISTICS

| Shot No. | Mach No. | $\delta_e^2$ (degree)$^2$ | $C_{m_\alpha}$ (1/rad) | $C_{m_q} + C_{m_\alpha}$ (1/rad$^2$) | $C_{m_{p_\beta}}$ (1/rad$^2$) | $C_{D_o}$ |
|---|---|---|---|---|---|---|
| 1 | 2.97 | 67.9 | 2.78 | -23.0 | 0.79 | 0.33 |
| 2 | 2.98 | 29.3 | 2.81 | -36.2 | 1.40 | 0.33 |
| 3 | 3.03 | 107.2 | 2.84 | -16.8 | 0.52 | 0.33 |
| 4 | 2.92 | 40.5 | 2.92 | -34.5 | 1.18 | 0.33 |
| 5 | 3.10 | 195.3 | 2.95 | -14.5 | 0.45 | 0.33 |
| 6 | 3.12 | 255.5 | 2.99 | -20.5 | 0.63 | 0.33 |
| 7 | 3.14 | 87.8 | 2.89 | -25.8 | 0.59 | 0.33 |
| 8 | 2.94 | 2.7 | 2.89 | No Data | No Data | 0.33 |
| 9 | 2.98 | 5.1 | 3.06 | No Data | No Data | 0.33 |
| Mean | 3.02 | - | 2.90 | -24.5 | 0.79 | 0.33 |

## LIST OF REFERENCES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